The Puget Sound Regional Synthesis Model (PRISM)

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The Puget Sound Region and PRISM

Puget Sound is an integral part of the life of the Pacific Northwest. The beauty and the value of its forests, waters, islands, and shorelines provide an irresistible lure for recreational, aesthetic, and commercial activities. But Puget Sound and its environs are undergoing changes induced by increasing population. At current rates of growth and patterns of urbanization, the region can expect to urbanize land area equal to the city of Tacoma every two years and the city of Portland every five years. Forests, wetlands, and estuarine habitats continue to decrease in area, water resources are over-subscribed, and sediments are increasingly polluted. Together, these effects have led to declining fish populations. If extended over decades, this cumulative degradation will increasingly compromise the viability of the region as a human resource.

One of the most significant challenges for the citizens of the Puget Sound and Georgia Basins is how to balance this population growth while maintaining the environmental integrity so important to the livability and economic viability of the region. Key to finding such a balance is to have a strategy, based on the most sound information possible, to determine the tradeoffs between alternative scenarios for the future. This strategy must include educating the citizens of the region about what the issues and consequences of decisions are, and creating tools to enhance communication among the key players. Current knowledge about Puget Sound is substantial, but fragmented; it is almost entirely descriptive and rarely "prescriptive." In practice, critical issues are divided up amongst multiple agencies and jurisdictions; each is responsible for a piece, but nowhere do they come together.

Developing such a strategy and bringing a common vision and process to the region is the goal of PRISM (the Puget Sound Regional Synthesis Model) a new, and new type, of project based at the University of Washington (UW). PRISM intends to develop and sustain a dynamic and integrated understanding and description of the environmental and human factors that will shape the Puget Sound region as it moves into the 21st century.

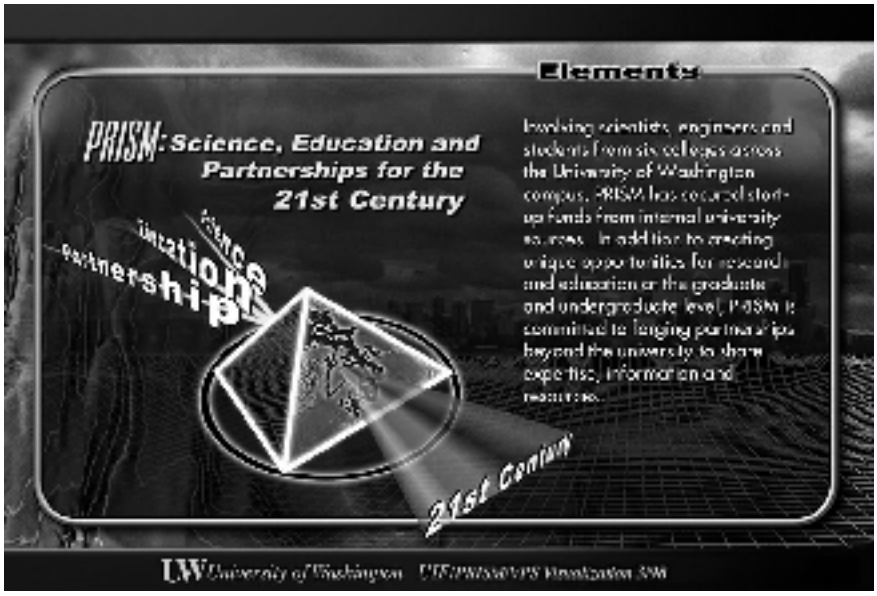
PRISM will be a "laboratory and classroom without walls," capable of traveling in time and in space to analyze multiple issues of the region. Its greatest resolution and accuracy will be in confronting the state of Puget Sound today, where access to information is the greatest and, hence, the ability to understand processes and to educate is the greatest. As we develop our ability to model the environment as it exists today (which provides some confidence on the limits of what we know and indicates what directions we must go), we can "zoom in" on periods of the past. The further we go back in time, the more blurry our vision becomes, but in the process we learn what the tradeoffs in analysis are. With the composite information from the present and past, the most challenging task will be to travel into the future, into the 21st century.

PRISM will address questions critical to the functioning of Puget Sound and surrounding watershed, and assess how the ecosystem responds to natural and human-induced (or anthropogenic) change. Answering these questions will allow us to focus on the major issues confronting the region:

- How does the landscape and seascape of Puget Sound function both as a natural system and in response to human activities across different time and space scales?
- What are the institutional and social forces that influence how society affects the Puget Sound environment, and how can these forces be better managed to both conserve and develop environmental resources?

PRISM will then consider how to derive and use the resulting information in education and in regional partnerships for the application of the information to regional needs:

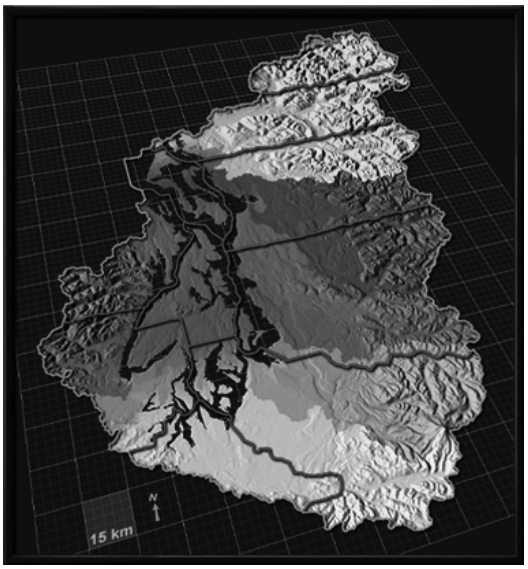
- How can the information and understanding obtained through PRISM be used as a means to integrate the component parts of the university and community to offer a high quality interdisciplinary education?
- How can the university best work with other public and private organizations as partners in understanding, managing, and learning about the Puget Sound region?



To do this, PRISM requires three concurrent elements:

- Science. Science represents the active synthesis of the multiple sources of information available in the region that must be brought to bear on the issues in an integrative, dynamic, and forward-looking manner. As will be described below, the vehicle for Information will be the creation and maintenance of a "Virtual Puget Sound" (VPS).
- Education. A Puget Sound-driven education program develops and in turn uses the understanding represented by the VPS as the vehicle to conduct the essential and unparalleled level of interdisciplinary learning required across the UW and out to the citizenry. PRISM education efforts are based primarily on the need to be responsive to new mandates to enhance the quality of undergraduate instruction and to provide more opportunities to undergraduates to participate in research activities. Consequently PRISM will provide both content to courses, and resources in the form of VPS information and/or data, running PRISM-supported modeling interfaces, or linking students in classes with researchers involved in PRISM. Conversely, PRISM is set up to benefit by student involvement in that students may be directly involved in data acquisition, model development, and analyses of Puget Sound cases that enhance the "accessibility" of PRISM to other students. Additionally, efforts to extend both PRISM content and technological resources to K–12 education will take place through pre-service and in-service teacher education opportunities, and through non-traditional educational outlets such as museums and nature centers.

- **Partnerships.** Data of interest to PRISM extend far beyond those collected by university researchers. PRISM is actively developing partnerships to integrate existing and new information about Puget Sound; these partnerships will facilitate the linking of biophysical and socioeconomic data from many sources including agencies, academic institutions, NGOs, and businesses. PRISM partnerships are conceived as being fully collaborative, where individuals with expertise in a particular topic work together on a common problem, regardless of institutional affiliation (often via the World Wide Web). In this manner PRISM will work to meet the information needs identified in an iterative methodology of user and task analysis. Ultimately PRISM partnerships will be judged not only on the utility of PRISM information, but on the ability to meet common goals that contribute to greater understanding and improved management of the region's natural resources.

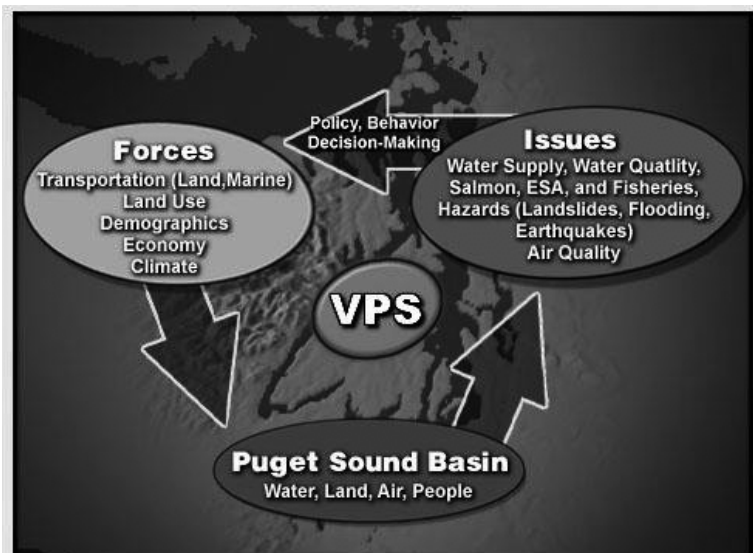


PRISM: Its Domain and Issues

The geographic area encompassed by PRISM includes the drainage basins (with forests, agriculture, and urban land), shorelines and estuaries, and the open water of the Sound itself. This domain requires understanding and tracking of fundamental ecosystem processes and events from mountaintops to ocean floor. Explicit is the recognition that political boundaries cross drainage basin boundaries (where government agencies do not typically operate). While the emphasis will be on Washington State waters, the contiguous ties with British Columbia are implicit. Such a perspective will be crucial as the population of Puget Sound expands and remaining vacant lands between Vancouver and Olympia become developed.

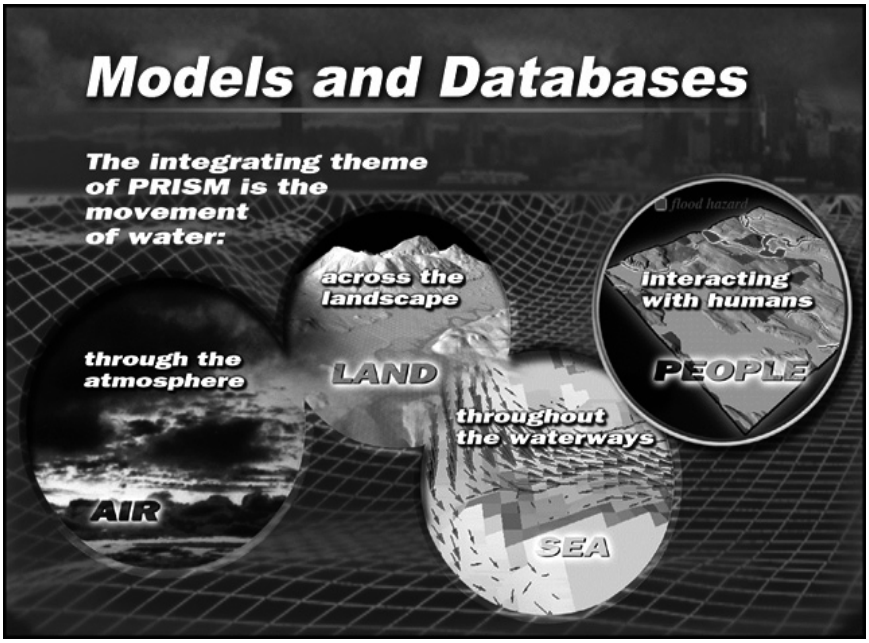
The focus of PRISM is to address a set of major environmental issues of the region that have the common denominator of the movement of water and its constituents from the atmosphere across the landscape and the seascape, and, hence, have a common basis for resolution. Climate and land use practices restructure the water cycle and have major impacts on the economy, biological productivity, and habitability of the region. Understanding and quantifying the water cycle including rainfall patterns, impacts of land use on stream flows and water quality, the impact on wetlands and estuaries and Puget Sound circulation are of first order importance for the Puget Sound community. Specific issues include water supply and quality (allocation, pollutant and contaminant fate, combined sewer outflows, eutrophication of lakes and the Sound), biotic resources (salmon and the Endangered Species Act, habitat integrity and diversity, harmful algae, local fisheries), and air quality. They include the major hazards the region faces, from flooding, landslides, and seismic activity.

The central operating principle of PRISM is that these regional "forces of change" operate upon a common biophysical structure. We can then treat the "issues" as being a set of tangible consequences created by how forces of change operate upon the Puget Sound Basin. That is, the forces of change are the specific impacts on the environment driven both by social or human actions (e.g., changes in transportation, demography, infrastructure, and technology) and by climatic variations (in rainfall or temperature). The world of Puget Sound is then represented as the "physical template" (below), with multiple time and space scales. It includes the basic structure of the basin (mountains, river basins, flatlands, cities, shorelines, and seafloor), the changes in the basin, which happen over time (the evolution of a forest into a subdivision), and the short-term dynamics (rainfall patterns causing floods, washing sediments into estuaries).



A Virtual Puget Sound

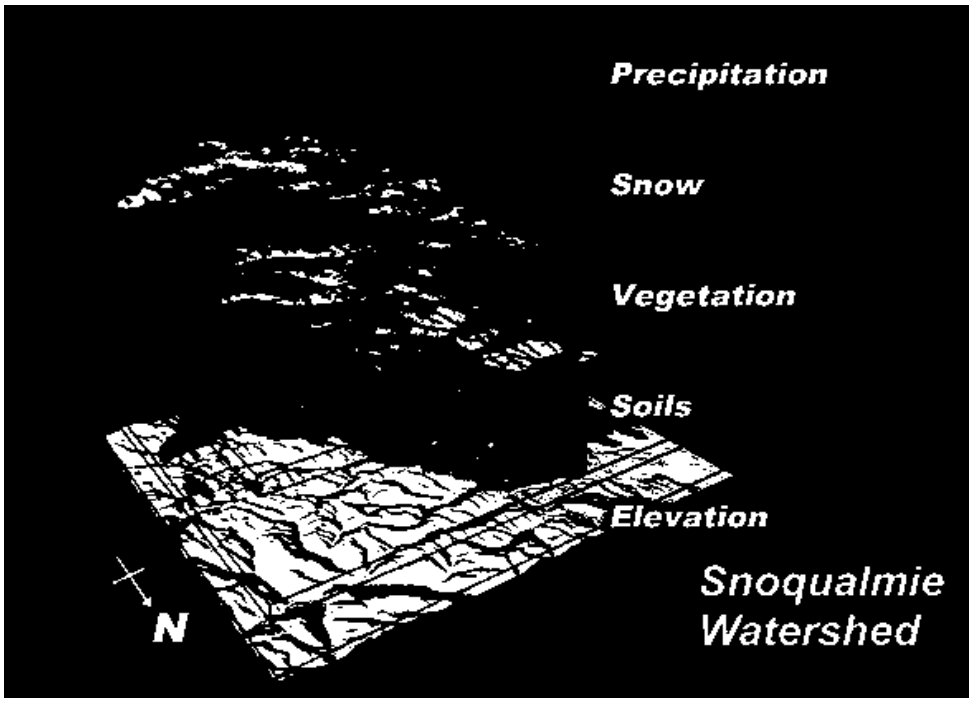
The primary vehicle for integrating the information requirements for the forces, issues, and Puget Sound Basin is the creation and nurturing of the "Virtual Puget Sound" (VPS). VPS will serve as a gateway to an interactive archive of integrated numerical modeling systems and databases. A series of modules describing the ecological and physical world of Puget Sound will range from basin-wide models and observations of the entire Puget Sound region to ultra-high resolution finite element models suitable for studies of specific sub-regions.



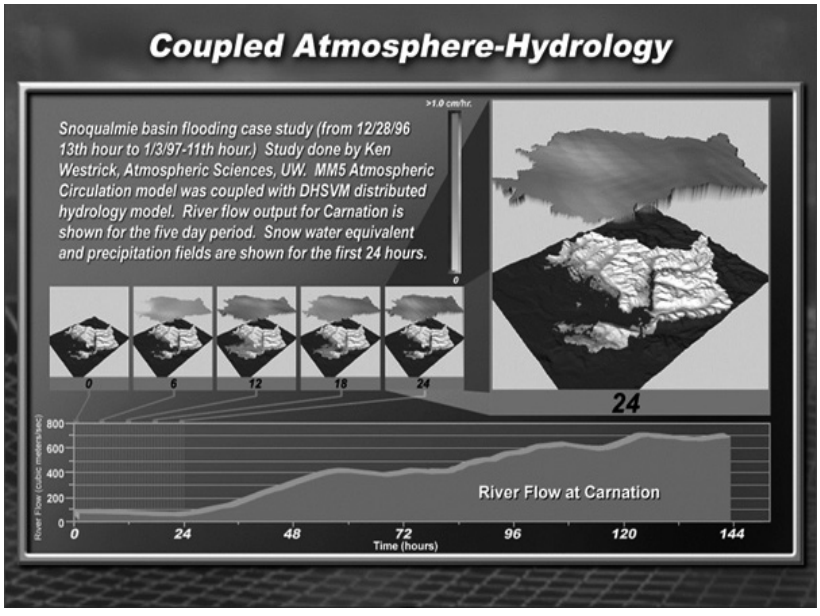
The modules of the VPS will be considered as distinct information systems, containing historical and real-time data (including regional government databases, current information on the state of the region, meteorological and hydrological information, land use, biological inventories, economic and demographic databases). The modules will also include database tools to access the information, spatial and statistical tools to work with the data, models to project future data states, and a database of literature pertaining to each module. They will link historical information, current conditions, and future

projections using the emerging network-based distributed database and model technology. The specific modules of VPS include:

The Physical Template



The basic information for the modules will consist of the "physical template," where the multiple data layers required to describe the land and Sound are assembled in spatial models (illustrated here for the Snoqualmie Basin). The basis of the physical template for the region is a spatial consistent digital elevation model (DEM) on which a flow-direction grid, and a modeled network of streams and basins can be calculated. The physical template is more then a GIS database of thematic layers, such as soils, vegetation, or land use. The physical template is the explicit statement of the relationship between these data layers over both space and time. From this perspective, the physical template becomes a geographically referenced description of the spatial and temporal dynamics of the region.

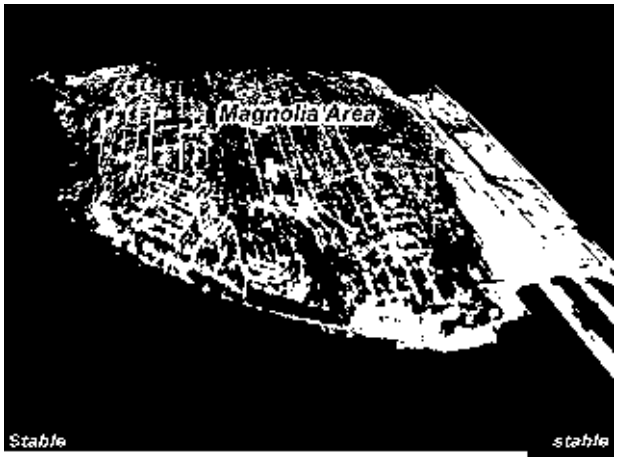


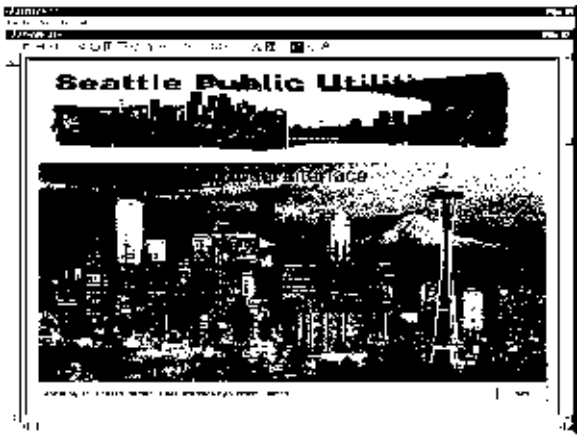
Coupled Atmosphere-Hydrology

An atmospheric regional weather module will provide high temporal and spatial resolution for such information, as rainfall and surface temperature required by the land-surface and water modules. Meteorological forcing for surface hydrology models is provided by the fifth-generation MM5 mesoscale atmospheric model: a limited-area, non-hydrostatic, sigma-coordinate model designed to predict mesoscale and regional-scale atmospheric circulations and surface exchanges. A consortium of local, state, and federal agencies now runs the MM5 to produce 48-hr weather forecasts at a 12-km spatial resolution for the entire Pacific Northwest and at a 4-km resolution over Washington

State. This model is initialized using both observations (both satellite and *in-situ*) and large-scale output from National Weather Service models. Finer-scale surface water movement is represented via the Distributed Hydrology-Soil-Vegetation Model (DHSVM), a physically-based, spatially distributed hydrologic model that explicitly solves the water and energy balance over a topographic grid with cells of typical dimension 30–200 m. DHSVM uses as inputs spatial image data and meteorological forcings from the MM5.

This hydrology model will then be coupled to water resource modeling and hazard prediction (flooding, landslides). Information on water distributions from the hydrology model will be integrated with the requirements of public utilities across the region. Landslides in the Seattle neighborhood of Magnolia, for example, can be predicted from a basic scientific understanding of how slides are produced combined with spatial data sets.





Puget Sound Circulation, Water Quality, and Nearshore habitat

A Puget Sound circulation and water quality module will receive inputs on atmospheric conditions and surfacewater discharge to describe currents in the Sound and potential movements of important nutrients and contaminants. A phytoplankton model, responding to the nutrient availability and to the short wave radiation data supplied from the atmospheric model, will forecast productivity in different locations of the Sound. Each model will be thoroughly validated using data collected in the past and being gathered by various state and local agencies. The Princeton Ocean Model, a three-dimensional, time-dependent, sigma-coordinate, numerical model now used extensively among coastal and estuarine researchers, is being adapted to represent the circulation and ecosystem structure of Puget Sound. This model includes realistic bathymetry and an accepted parameterization of turbulent mixing. It is forced by realistic tides and river flows (from the hydrology modules), and has been run to simulate Puget Sound circulation and stratification for a model year. Biology and chemistry are being incorporated.

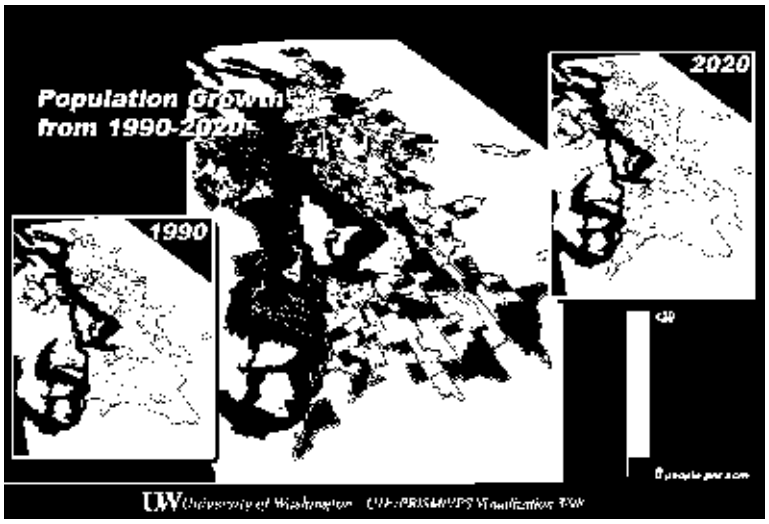
PRISM will complement these efforts by conducting observations at crucial points using moored and bottom-mounted arrays, shipboard observations (both from the UW research vessels and through collaborative arrangements with shipping concerns such as Washington State Ferries), and by means of remote sensing. Of particular importance will be monitoring of the entrance of Admiralty Inlet from the Strait of Juan de Fuca, through a combination of moorings and shipboard observations, temperature, salinity and current to give a boundary condition to the circulation model, and flux of nutrients into the Sound.

The focus of the marine biological communities module will be to describe nature and extent of historical change in shoreline, inter- and shallow water sub-tidal habitat, with an emphasis on major commercial and recreational fisheries species (e.g. bivalves, crabs, shrimp, flatfishes, salmonids). A hierarchy of marine habitats will be defined for inter-and sub-tidal areas of Puget Sound based on major assemblages of flora and fauna, physio-chemical attributes, as linked to riverine and watershed features. Spatial distribution will be derived from present day resource atlases and historical documents back to the 1870s. These databases will be used to build simulations derived from the "Circulation and Physical Processes" group to study outcomes of scenarios for remedial actions (e.g., return of diked land to wetlands habitat for salmon), or consequences of further human perturbations (e.g., spread of exotic species).

The Human Dimension

The PRISM human dimension currently includes two components: (a) the impacts of human action on the biophysical system, and (b) the socioeconomic effects of environmental change in the Puget Sound. Human decisions will be treated explicitly through the development of an urban ecosystem model (UEM), ultimately addressing how population changes over time might affect the region.

This model will predict the environmental stresses associated with urban development and land use change under alternative demographic, economic, and policy scenarios. Urban development is a dynamic outcome of the interactions between the choices of many actors including households, businesses, developers, and governments. These actors make decisions that alter the patterns of land use and human activities. UEM will be designed to model spatially explicit processes that link these decisions to changes in the Puget Sound biophysical structure. PRISM will build on existing urban simulation models to predict four types of human-induced environmental stressors: land conversion, resource use, emissions, and other physical modifications that affect the habitat of specific species. The initial focus will be on modeling changes in land use and land cover. The model is object-oriented and builds on an existing urban simulation model (UrbanSim) to predict the location behaviors of households, businesses, and developers. Production and consumption behavior will be added to households and businesses and linked through a grid representation of land to infrastructure and natural systems. Governmental choices about urban growth, zoning, infrastructure, and pollution control policies are exogenous to the model. The core location model in UrbanSim will also be revised from its current aggregate structure to one based on micro-simulation, and from a zone description of space to one based on a high resolution grid structure. Using UrbanSim predictions as an input, changes in land use and cover will be modeled using a multinomial logit-model based on a set of land use and cover determinants including original use, accessibility, environmental conditions, cost of conversion, and policy constraints. The model will provide parameter estimations to calculate land use and cover transition probabilities. The output of the urban ecosystem model will serve as the input to several biophysical models including the hydrology, hill-slope stability, water quality, atmospheric, and aquatic and terrestrial ecosystem models.



A socioeconomic impact model will estimate the direct and indirect effects of the changes in the Puget Sound biophysical structure on property value, income, health and quality of life. The current focus of the socioeconomic model is on the potential impacts of flood and landslide events. Stakeholders concerns and interests that are related to these impacts are also mapped to identify the differential impacts on various economic and social groups.

The biophysical and the human dimensions will be linked through an integrated assessment model. Development of such an integrated model will provide a framework to answer relevant policy questions for the Puget Sound. More specifically scientists in such areas as marine affairs, urban planning, engineering, and resource management will work with natural systems scientists to develop an integrated view that satisfies both the natural and social sciences. This integrated framework will constitute the basis to describe causal relationships and interactions at a variety of spatial and temporal scales. A decision-support system will be devised to evaluate the impacts of current trends and alternative futures in terms of social and economic benefits and costs, as well as in terms of environmental values and benefits. This system could be used to determine who pays for, and who benefits from, changes in land use, resource management and other regulatory actions that affect Puget Sound. The integrated assessment model and decision support system will allow policy makers, students, and researchers to determine scenarios that maximize benefits to the Puget Sound environment and to human society. Changing how society relates to Puget Sound will require changes in the behavior of large organizations and institutions, businesses, households, and individuals. PRISM will develop models and analyses of regulations and behavioral patterns that determine land use, resource management, and waste disposal in order to make better predictions of the impact of future actions on the natural environment and on social benefits. From these predictive models, policy makers, scholars, and citizens can devise best practices for human activities and behaviors to sustain and enhance the Puget Sound environment over the next century.

The process of collaborations visualization, communication, and computer graphics have advanced to a stage that cooperative work between units is viable and the distribution of graphical output to university and community groups is possible. PRISM will determine how to make a heterogeneous collection of complex scientific models available in a uniform way and provide general mechanisms for coupling them. It will examine how to handle multiple scales in both space and time, and how to visualize the vast amount of information required. To promote consensus on purposes and to assess our current state of knowledge and capabilities, a goal of the VPS is to serve as a forum for evaluation of alternative approaches. The execution of VPS will be via the World-Wide Web.

What is Unique About PRISM?

PRISM is intended to help address issues played out daily in the newspapers across the region. The establishment, verification, and continuous refinement of the Virtual Puget Sound environment will provide a powerful tool for education and outreach. Model output will be made available in real time and retrospectively through the World Wide Web and other media. Once improved to a state of considerable realism, the VPS will be used for evaluating the effects of changes in land management and other environmental changes. By contributing to the capability of the region to make optimum use of its resources, the sustainability and viability of the Puget Sound Basin should be promoted.